Relationship between gilt behavior and meat quality using principal component analysis

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Abstract

Pig on-farm behavior has important repercussions on pig welfare and performance, but generally its relationship with meat quality is not well understood. We used principal component analysis to determine the relationship between meat quality traits, feeding patterns, scale activity, and number of conflict-avoidance interactions. The first principal component indicated that gilts with greater daily feed intake stayed longer in the feeder and their meat had increased intramuscular fat (IMF), was lighter in color, and, in the second principal component, had better juiciness, tenderness, chewiness, and flavor. Meat from gilts with lower scale activity scores appeared to have more IMF but greater drip losses (DL). The third principal component suggested that dominant gilts could gain priority access to the feeder, eating more and growing fatter. In conclusion, gilt scale activity and conflict-avoidance behaviors were not good indicators of final meat quality attributes, except perhaps IMF and DL.

Key words: activity scores, conflict-avoidance, intramuscular fat, pork, tenderness, water-holding capacity

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1. Introduction

Pig behavior is the aggregate of pig actions and reactions in response to internal and external stimuli. Understanding and selecting for beneficial behaviors is very important for successful management, performance, economical return, and overall pig welfare. Individual genetic variance exists in behavioral traits and so, these traits can be used in selection programs (van Erp-van der Kooij, Kuijpers, van Eerdenburg, & Tielen, 2003; Turner et al., 2006; Holl, Rohrer, & Brown-Brandl, 2010). For example, a beneficial selection trait for pigs would be the ability to cope with pre-slaughter stress during the marketing process, or a reduction in aggression when group housed (Lawrence et al., 1991; Turner et al., 2006). At the same time, selection with a singular focus on performance traits may induce changes in behavior that are detrimental to the individual or group of pigs. For example, negative impacts in their feeding patterns (Young, Cai, & Dekkers, 2011) or increases in aggression (van Erp-van der Kooij et al., 2003) may result from such selection.

At Iowa State University, a line of purebred Yorkshire pigs has been selected for decreased residual feed intake (RFI), alongside a randomly bred control line. After 4 generations of selection, the Low RFI line required 6% less feed for the same amount of growth and backfat (Cai, Casey, & Dekkers, 2008). Sadler, Johnson, Lonergan, Nettleton, & Dekkers (2011) reported behavioral differences between the two genetic lines, with Low RFI gilts becoming less active. However, the relationship between feeding patterns and conflict-avoidance behaviors (within the pen and around resources) of Low RFI pigs on their final meat quality is not well understood. Therefore, the objective of this investigation was to determine the extent to which on-farm feeding and social behaviors affect fresh pork loin composition and quality using principal component analysis.

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2. Materials and methods

2.1. Animals

All procedures involving live animals were approved by the Iowa State University Animal Care and Use Committee (approval number 12-07-6482-S). Data from 192 purebred Yorkshire gilts were used. These gilts belonged to a selection experiment for decreased RFI, conducted from April 15 to August 14, 2008. One-half of the gilts were from a line that had been selectively bred for decreased RFI over 5 generations (Low RFI) and the other one-half from a randomly selected bred control line. Development of these lines was described in Cai et al. (2008). The experimental design was a randomized complete block design, with pen as block and individual pig as the experimental unit. Gilts were placed on test in 2 groups and housed in 12 finishing pens with 8 pigs from each line in each pen at an average of 98.9 (SD 8.2) d of age and 40.3 (SD 5.8) kg. They were fed *ad libitum* a diet formulated to meet or exceed nutrient requirements. Gilts were slaughtered in a commercial facility at an average of 214.2 (SD 16.0) d of age and with an average body weight of 111.7 (SD 6.6) kg.

2.2. Feeding patterns

Gilt feeding patterns of 173 gilts were collected using an electronic single-space feeder (FIRE, Osborne Industries Inc., Osborne, KS). Feed intake was recorded one week after placement and until the first gilts reached the targeted market weight of 110 kg. Average daily feed intake was derived by summing feed intake of each pig per day and averaging across days. Average number of visits to the feeder per day was calculated by averaging the number of visits per day by pig. Average feed intake per visit to the feeder was calculated by averaging feed consumption by visits across days. Average occupation time per day and average occupation time per visit were calculated in a similar manner as daily feed intake and

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feed intake per visit. Average feed intake rate was obtained by dividing the amount of feed consumed by the time spent in the feeder and then averaging the individual visit feeding rates.

2.3. Scale activity scores

Gilts were evaluated for scale activity when they were weighed. Scale activity scores were collected for individual gilts once the weigh scale back gate was closed. Scale activity was on a 1 through 5 scale (1 = calm, minimal movement; 2 = calm movement, including the gilt walking forward and backward at a slow pace; 3 = continuous fast movement, including quickly walking forward and backward; 4 = continuous rapid movement and vocalizing; 5 = continuous rapid movement and an escape attempt). This scale activity score was modified from Rempel, Rohrer, & Brown-Brandl (2009). Two trained researchers assigned two scale activity scores to gilts, and the mean value was used. The successive evaluations took place at the same established measurement/evaluation periods for all animals (called rounds). They started one week after placement (round 1) and subsequent evaluation periods (rounds 2 to 10) took place every two weeks until gilts reached their targeted market weight. Most gilts underwent a minimum of 7 evaluation rounds (n = 188).

2.4. Conflict and avoidance interactions in the home pen

Video was collected on the day of placement and then every four weeks until the end of the study, for a total of 4 recordings. Video was collected from 0800 h to 2000 h (12 h), and then the four most active hours of the day were used. The four pre-determined active hours were 0700 to 0900 and 1600 to 1800 h. This resulted in 16 h of video/gilt. Gilts were individually marked with an animal-safe paint stick (Prima Tech Retractable Marking Sticks, Prima Tech, Kenansville, NC) on their backs the day before recording. Twelve color cameras (Panasonic, model WV-CP484, Matsushita Co. Ltd., Kadoma, Japan) were placed over the

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pens and video was collected onto a DVR (Reco, Darim Vision, Pleasanton, CA) at 10 frames/s (Sadler et al., 2011). Seven mutually exclusive conflict-avoidance behavioral events were scored that occurred in the home pen (Table 1). The number of conflict-avoidance events that occurred within one gilt body length around the feeder or drinker was recorded. Gilt behaviors were collected by two experienced observers using the Observer software (The Observer, version 5.0.31 Noldus Information Technology, Wageningen, the Netherlands). Training was conducted to ensure reliability and a final agreement of 98% was reached.

2.5. Meat quality

Meat quality traits were measured in loin chops from 169 gilts (Smith et al., 2011). Ultimate pH was measured at 48 h postmortem using a Hanna 9025 pH/ORP meter (Hanna Instruments, Woonsocket, RI) with a penetration probe. Boneless chops were trimmed free of subcutaneous adipose tissue and were homogenized and prepared to measure intramuscular fat content (IMF) (AOAC, 1990). Hunter L, a, and b values were determined on two chops in triplicate at 1 d postmortem using a calibrated Hunter Labscan colorimeter (Hunter Association Laboratories Inc., Reston, VA). The colorimeter utilized a C10 illuminant to obtain color scores using a 10º observer and 1.27-cm aperture. The 6 color readings were used to calculate the average value for each chop. Drip loss (DL) was determined at 3 d postmortem on two chops per loin. Chops were trimmed of external fat, weighed, and stored in a sealed plastic bag at 4 ºC. After 24 h of storage, the liquid lost was removed from each bag, the chops were blotted of excess moisture and reweighed, and DL was calculated as the percentage of liquid lost with respect to the original weight of the chops. Water-holding capacity (WHC) was assessed using a centrifugation method, also at 3 d postmosterm. Duplicate 10-g minced samples were placed into centrifuge tubes and centrifuged for 10 min at 40,000 *g* at 4 ºC. After centrifugation, the liquid was removed, and WHC was recorded as

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percentage of the final weight of the samples in respect to the original weight. A trained sensory panel (n = 4) scored cooked chops for sensory quality traits at 7 to 10 d postmortem. The chops were cooked on clamshell grills to an internal temperature of 70 ºC. The temperature of each chop was monitored individually using thermocouples (Omega Engineering Inc., Stamford, CT). The chops were cooled to room temperature before analysis. Four cubes were cut from the center of the chop and each panelist evaluated the samples for the cooked chops juiciness (1 = not juicy; 15 = very juicy), tenderness (1 = not tender; 15 = very tender), chewiness (1 = not chewy; 15 = very chewy), and flavor (1 = little pork flavor, bland; 15 = extremely flavorful, abundant pork flavor). Sensory data were recorded using a computerized sensory software system (Compusense five 4.6, Compusense, Inc., Guelph, Ontario, Canada).

2.6. Principal component analysis

A principal component analysis (PCA) was performed using the statistic package JMP 8 (SAS Institute Inc., Cary, NC) with the data of both lines together. The correlation matrix between scale activity scores was examined to reduce the high number of variables in the analysis. Moderate correlations were observed among the scale activity scores in the initial rounds (e.g., mean correlation through rounds 1 to 4 was 0.26, SD 0.06) and in the last rounds (e.g., mean correlation through rounds 6 to 9 was 0.29, SD 0.08), but the correlations between initial and final rounds were low (mean correlation between these two groups of rounds was 0.12, SD 0.09). Scale activity scores from the first three rounds were chosen to represent the scale activity at the beginning of the trial (early fattening period). As the number of rounds that each gilt underwent varied from 7 to 10, the scale activity at the end of the trial (later fattening period) was represented by scale activity scores from the three last rounds that each gilt underwent before slaughter, involving information from rounds 5 to 10 depending on the

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animal. The mean correlations among the scale activity scores in the PCA were 0.26 (SD 0.06) in the first to third rounds and 0.27 (SD 0.10) in the second to last to ultimate rounds, but only 0.09 (SD 0.06) between both groups. A summary of the variables of each category included in the PCA is given in Tables 2 to 5. The coefficients (loadings) of the eigenvectors for the first three principal components were determined (Karlsson, 1992). The relevance of each variable in each principal component was calculated as the percentage of the absolute value of its loading with respect to the sum of the absolute values of all the loadings in the eigenvector (Karlsson, 1992). Based on the obtained relevance values, we considered a variable as represented enough in the principal component if its relative relevance was above 4.0%. Possible line trends were assessed using a t-test of their differences ($P \leq 0.05$), both for the individual traits (Tables 2 to 5) and the principal component scores, and by inspection of the distribution in the biplot of the principal component scores of the gilts.

3. Results

The loadings of the eigenvectors and the relevance of each loading for the three main principal components are presented in Table 6. The first principal component (PC1) explained 11.1% of total variance. The most important meat quality traits in PC1 were IMF and WHC, followed by DL, pH, and Hunter L. Feed intake variables were also relevant in PC1, with the exception of occupation time per day and feed intake rate. The scale activity scores in the third round and at the end of the trial also showed high loadings, but not in the first and second rounds.

The second principal component (PC2) explained 9.1% of total variance. The trained sensory panel scores for organoleptic quality were strongly represented in PC2. The loading for DL was also above the fixed threshold for relevance. Apart from these meat quality traits, only amount of feed intake (daily and per visit) was relevant.

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The third principal component (PC3) explained 8.2% of total variance and accounted for a combination of variables including IMF and Hunter b, as well as occupation time and number of visits per day, amount of feed intake per visit, feed intake rate, the number of times that gilts engaged in fight, bully, and head knock, and the number of times that these conflict-avoidance interactions took place around the feeder.

The PC1 and PC3 scores of the Low RFI gilts were significantly lower than those of the control gilts ($P < 0.01$), but not for PC2 (data not shown). The main variables in PC1 and PC3 are represented in the biplot (Fig. 1). Although overlapping, the Low RFI gilts clustered in the lower left area and the control ones in the upper right. This separation trend was mainly attribuitable to IMF and feeding pattern variables.

4. Discussion

Due to the large number of variables and the low correlations among groups of variables (data not shown), each principal component explained a low percentage of total variance. This situation forced us to adopt a low threshold for relative relevance (>4.0%) to consider or reject a variable as represented enough in each principal component. Because the PCA was performed with data of both lines together, results refer to the whole population, but they must be interpreted with caution in light of the low percentage of total variance explained. Previous studies have also found low and mostly insignificant phenotypic correlations among performance (e.g., van Erp-van der Kooij et al., 2003; Velie et al., 2009; Holl et al., 2010; Yoder et al., 2011) or meat quality (e.g., Beattie, O'Connell, & Moss, 2000; Klont et al., 2001; Morrison, Johnston & Hillbrands, 2007; D’Eath et al., 2010) and behavioral traits.

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4.1. Feeding patterns and relationship to final meat quality attributes

The PC1 indicated that IMF was positively related with the amount of feed intake and negatively with the frequency of the visits to the feeder. Gilts that ate more, both daily and per visit, deposited more IMF. The positive relationship between feed consumption and carcass fatness, including IMF, is well-established (de Vries, van der Wal, Long, Eikelenboom, & Merks, 1994; Gilbert et al., 2007; Cai et al., 2008). These gilts also tended to visit the feeder less times per day than the leaner gilts but to occupy them longer, which is in agreement with Von Felde, Roehe, Looft, & Kalm (1996), Rauw, Soler, Tibau, Reixach, & Gomez Raya (2006), and Young et al. (2011). Gilts with more fat tended to have lower pH and WHC and greater DL. The positive relationship of pH with WHC and negative with DL was in agreement with previous findings (Huff-Lonergan & Lonergan, 2005). Knapp, Willam, & Sölkner (1997) reported different trends depending on breed between IMF and the meat quality traits pH at 45 min and DL. They found null phenotypic correlations in Yorkshire and Pietrain, and unfavorable in Landrace, although a favorable relationship in Landrace, as well as Duroc, was found in another study (Gjerlaug-Enger, Aass, Ødegård, & Vangen, 2010). Other studies also reported null correlations between IMF and both pH and DL in Yorkshire populations (de Vries et al., 1994) and in a Berkshire×Yorkshire cross (Huff-Lonergan et al., 2002). Also in Yorkshire pigs, de Vries et al. (1994) and Gilbert et al. (2007) found positive relationships of feed intake and RFI with pH and negative with DL. These relationships were not strong for all the traits and inconsistent with our findings. Therefore, caution should be taken before inferring the relationships of pH, WHC, and DL with IMF and feed intake from PC1, due to the null phenotypic correlations generally found between these traits in Yorkshire populations. The greater Hunter L values (lighter color) in meat from fatter gilts could be attributable to the greater levels of IMF (Schwab, Baas, Stalder, & Mabry, 2006).

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The PC2 mainly accounted for the scores by the trained sensory panel. The perception of juiciness, tenderness, and flavor were positively related among them and with amount of feed intake (both per day and per visit), and negatively with chewiness. According to PC2, greater feed intake would lead to juicy, tender, not chewy, and flavorful meat, resulting in enhanced overall sensory quality. There is a general agreement about the existence of a favorable relationship between IMF and sensory traits (Huff-Lonergan et al., 2002; Wood et al., 2008), but there is some controversy about its extent and some studies failed to find any relationship. Lonergan et al. (2007) suggested that the effect of IMF could only be detected at the range of pH between 5.50 and 5.80, corresponding to intermediate sensory quality meats. Most of the samples in our study were within this pH interval (Table 2). As IMF was a relevant trait in PC1 but not in PC2, it is unclear if IMF plays a part in increasing tenderness, although both meat quality traits are enhanced by feed intake. The loading of DL was also above the established relative relevance threshold but its relationship with the amount of feed intake was inconsistent with the one displayed in PC1. Smith et al. (2011) reported greater calpastatin activity in Low RFI gilts (that tended to eat less; see Fig. 1), resulting in less postmortem degradation of the protein desmin by calpain proteinases. Postmortem degradation of desmin is linked to tenderization during aging and increased WHC (Huff-Lonergan, Zhang, & Lonergan, 2010). This would be consistent with the negative association between DL and amount of feed intake found in PC2 but opposite to the loadings in PC1. The nature of the possible association between reduced feed intake and less postmortem proteolysis should be further assessed.

4.2. Scale activity scores and relationship to final meat quality attributes

In PC1, the opposite signs of the loadings of scale activity scores with respect to IMF and daily feed intake indicate that gilts with lower scale activity scores showed also greater

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IMF and daily feed intake. This finding was in agreement with the results by Holl et al. (2010) and Yoder et al. (2011) showing a similar association of low scale activity scores with greater growth rates and fatter carcasses (greater backfat thickness). Similarly, greater backtest scores (number of attempts to escape when the piglet is put on its back and restrained to this position) were reported to be associated to leaner carcasses by van Erp-van der Kooij et al. (2003). It has been hypothesized that animals with greater scale activity scores (and similar tests scores) may have greater activity level and greater energy expenses. Previous work in cattle by Nkrumah et al. (2007) showed an association of excitable temperament (more rapid flight speed when exiting a squeeze chute) with reduced feed intake, slower growth, and leaner carcasses. In tropically adapted cattle breeds, Kadel, Johnston, Burrow, Graser, & Ferguson (2006) found that animals with more favorable chute scores and flight speed scores had more tender meat. We did not find a relationship between scale activity scores and tenderness. Kadel et al. (2006) also analyzed the relationship of what they described as temperament with Minolta color space coordinates and cooking loss percentage, but their analysis did not include any other meat quality traits. They found a negative relationship with cooking loss percentage, which would be in agreement with our findings because Smith et al. (2011) showed that DL and cooking loss percentage were positively correlated. In general, the genotypic correlations between the scale activity scores and the meat quality traits previously reported were higher than the phenotypic correlations, which were often not significant (Kadel et al., 2006; Nkrumah et al., 2007; Yoder et al., 2011). Only the loadings for the third round and for the rounds at the end of the trial were above the relevance threshold. The last scale activity score rounds might be better indicators of meat quality attributes because they are closer in time to processing.

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4.3. Conflict and avoidance interactions in the home pen and relationship to feeding pattern and final meat quality attributes

In PC3, fighting, bullying, and head-knocking were relevant, together with events at the feeder area. Push, chase, threat, avoidance, and events at the drinker occurred rarely and only occurred in a few gilts in this trial and so, their variability was low. Other traits involved in PC3 were IMF, Hunter b, scale activity score at the first round, and several feeding pattern traits. A greater number of conflict-avoidance interactions were found to be associated with greater IMF. We also found a positive association between conflict-avoidance interactions and occupation time per day. An explanation for these relationships could be that gilts engaging in more conflict-avoidance interactions might be dominant gilts that access the feeder more frequently (Brouns & Edwards, 1994), while gilts with less conflict-avoidance interactions might be lower in the hierarchy and spend less time close to the feeder. Unfortunately, dominance and social hierarchy in our population was not testable, but dominance and aggressive behaviors have been found to be positively correlated in previous reports (McGlone, 1986). If this hypothesis was true, the positive associations also found with number of visits per day and the negative associations with feed intake per visit would be inconsistent with reports by McGlone (1986) and Brouns & Edwards (1994). These authors observed that subordinate gilts were displaced more often from the feeder and had to visit it more times and eat less per visit than their dominant counterparts. However, although the loadings of PC3 for these two traits would contradict this, the loadings of PC1 (with the opposite sign) would be in agreement with it, that is, that fatter gilts eat in fewer visits to the feeder per day but eat more per visit. This inconsistency between PC1 and PC3 for both traits could be due to spurious relationships, because their differences between lines were not significant, as opposed to the strong differences for the other feeding pattern traits (Table 3; Young et al., 2011). Regarding feed intake rate, according to PC3, dominant fat gilts would

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also eat slower than docile lean gilts. This would disagree with the results of Von Felde et al. (1996) and Rauw et al. (2006) showing greater rate of feed intake is associated with greater daily feed intake, growth rate and backfat thickness. The results suggest that conflict-avoidance behavioral events in the home pen or around resources within a pen are not associated with meat quality attributes except IMF.

5. Conclusion

Gilts with greater daily feed intake tended to stay longer inside the feeder and had increased IMF. The greater levels of IMF could be making the meat lighter in color and enhancing the tenderness, juiciness, chewiness, and flavor. Low scale activity scores could be related to greater IMF deposition but also to greater DL. Gilt number of conflict-avoidance interactions were not good indicators for final meat quality attributes except IMF.

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Caption for Fig. 1

Fig. 1. Biplot for the first and third principal components (PC1 and PC3, accounting for 11.1% and 8.2% of total variance, respectively). The rays represent the loadings of the most relevant variables (Table 6) and the points represent the scores of the gilts from the Low RFI and control lines.